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Article

Smallholder Farmers' Knowledge, Perception and Management of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on *Zea mays* at Irrigation Schemes in Limpopo Province, South Africa

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Abstract: The fall armyworm, *Spodoptera frugiperda*, arrived during the 2016/2017 cropping season in Limpopo, South Africa and it continues to cause devastating damage on maize in this region. The present study investigated knowledge, perception and management of *S. frugiperda* by smallholder farmers at Dzindi and Tshiombo irrigation schemes in this region. The study was conducted in 16 focus group discussion interviews, 12 at Dzindi and four at Tshiombo irrigation scheme. Although farmers failed to identify *S. frugiperda* eggs and pupal stages, they positively identified the pest by its larval stage and refer to it by several local names. All farmers relied extensively on insecticides for *S. frugiperda* control. With the exception of the Dzindi irrigation scheme farmers, who have adopted Bt maize, very few farmers have adopted alternative methods to chemical control such as mechanical control, physical control (crushing egg and handpicking of larvae), biological control, cultural practices (such as Push-Pull Technology), possible indigenous knowledge, or the use of monitoring tools, for the management of *S. frugiperda*. The study provided valuable information for designing sustainable management practices to control *S. frugiperda* on maize in smallholder farming communities

Keywords: fall armyworm; focus group discussion; insect pest management

1. Introduction

Maize (*Zea mays*) is one of the main staple crops to over 300 million people in Africa [1]. Smallholder farmers are the main maize producer in Sub-Saharan Africa. They produce maize on approximately 40 million ha of land [2]. Smallholder farmers utilize maize in various ways. Green maize is harvested, sold and eaten roasted or boiled, whereas dry milling of maize grain may produce maize mealie, maize flour, corn oil, pop corns and other industrial uses such as alcoholic beverages [3]. Various abiotic stresses (such as poor soil fertility and drought) [4], socio-economic constraints (including lack of access to new technologies such as improved seed cultivars), poor infrastructures, and high cost of fertilizers and pesticides [5] limit maize production. Further, biotic stresses, including weeds (e.g. *Striga*), [6] pathogens (e.g. gray leaf spot, downy mildew and maize lethal necrosis), and insect pests (e.g. the maize stalkbores *Busseola fusca* and *Chilo partellus* [7] and the recent arrival in Sub-Saharan Africa, *Spodoptera frugiperda*) [8] put additional threat to maize production.

Spodoptera frugiperda, also known as the fall armyworm (FAW) is native to America [9] and was first confirmed in South Africa in 2017 [10]. *Spodoptera frugiperda* has a holometabolous life cycle which includes egg, six larval instars, pupal and adult stages. It is the *S. frugiperda* larvae that are

responsible for damage of more than 353 host plants from 76 different families which include Poaceae, Fabaceae, Solanaceae, Asteraceae and Rosaceae [11]. While cereals such as wheat, sorghum and maize are the main host of *S. frugiperda*, its preference is maize [12]. *Spodoptera frugiperda* larvae feed on both vegetative (developing leaves, stem, and whorl) and reproductive (tassel, ear, kernel and silk) parts of the maize plant [13]. The feeding of *S. frugiperda* on maize results in reduced quality leading to yield losses. The potential yield loss from *S. frugiperda* damage on maize in Africa is currently estimated at US\$ 9.4 billion [14]. Yield losses due to *S. frugiperda* reduce household income and threatens food security, especially for smallholder farmers in African communities [15]. This is attributed to increased cost of production due to increased labour and pesticide costs for controlling *S. frugiperda*.

Although studies have indicated that effective control of any insect pest requires Integrated Pest Management (IPM), it is not applicable to all farmers due to variations in their socio-economic conditions [16]. Integrated Pest Management requires correct identification of the pest and financial resources to purchase pesticides, traps and improved seeds, that most smallholder farmers in rural communities cannot afford [12].

Understanding smallholder farmers' knowledge (what they know about the biology, ecology and behaviour), perception (how farmers perceive *S. frugiperda* infestations, damage caused by this pest and the effectiveness of the management practices they have adopted) and practice (what they currently do), as well as their challenges in controlling pests are important for the development of research designed for sustainable integrated management. For example, understanding smallholders' perceptions about biological control can provide an insight into their motivation to apply or not apply pest management methods that use natural enemies [17]. Similarly, understanding smallholder perception on GM/Bt maize technology may provide answers on its adoption as well as compliance to those already planting Bt maize [18]. It is also important to understand farmer's indigenous knowledge and strategies they use to control insect pests. Such information is useful for researchers in designing IPM strategies that can meet their needs. However, information regarding smallholder farmer's perception, knowledge and management of *S. frugiperda* is limited and varies among maize producers. Emerging evidence suggests that *S. frugiperda* management practices varies among farmers in Ethiopia, Kenya [19], Malawi [20] Mozambique [21], Zimbabwe [22], Ghana [23] and Zambia [24]. However such studies are lacking in South Africa.

The present study investigated the perception, knowledge and management practices for *S. frugiperda* of smallholder farmers in the Dzindi and Tshiombo irrigation schemes of Limpopo province, South Africa. The study was conducted using focus group discussions, including groups of different gender and age classes. Discussions assessed knowledge of the identification of the pest; management practices; source, frequency and efficacy of insecticides; and the use and compliance of Bt maize. Results from this study will help to inform pest management strategies in this region.

2. Materials and Methods

2.1. Study Site Description

The study was conducted at the Dzindi and Tshiombo irrigation schemes in the Thulamela Municipality, Vhembe District, Limpopo Province of South Africa. The two schemes are about 45 km apart.

Dzindi (23°01'S; 30°26'E) is a smallholder irrigation scheme which was constructed in 1954. The scheme is situated 6 km south-west of Thohoyandou, a main town in Vhembe District. It is a surface irrigation scheme that covers an area of about 136 hectares. The production area is divided into four separate blocks subdivided into 106 plots of approximately 1.28 hectares each. There are 25 plots in Block 1, 35 in Block 2, 13 in Block 3 and 33 in Block 4. Irrigation water is supplied by a diversion of the Dzindi River, a perennial river flowing south of Itsani village through a concrete weir. A concrete canal distributes water for irrigation. Concrete furrows bring the water to the farmers' plots. The distribution of furrows has been designed to allow water to enter the fields at a regular interval. In three of the four irrigation blocks, the main canal directly supplies the secondary

distribution furrows, which brings the irrigation water to the plot edge. In Block 1, the channel provides water to an earthen dam, from where it is transferred to the distribution furrows and the plots. Farmers rotate maize in summer and vegetables in winter.

Tshiombo irrigation scheme (S 22°47.863; E30°27.194) was constructed between 1959 and 1964. It is situated 40 km north-east of Thohoyandou. It is the largest irrigation scheme in the Limpopo Province, covering 1196 hectares of production area in the western end of Tshiombo. The scheme covers seven villages in which the smallholders live: Matangari, Tshiombo, Maraxwe, Mianzwi, Matombotswuka, Mbahela and Mutshenzheni. The scheme is subdivided into 1041 plots, each 1.2 hectares in size. Maraxwe has 96 plots, Mutshenzheni 47 plots, Matombotswuka 201 plots, Tshiombo 115, Mianzwi 97, Maraxwe 100, Mbahela 100 and Matangari 285. The Mutale river borders the Tshiombo irrigation schemes on the north and the Mudaswali river on the east. Farmers plant maize throughout the year. Therefore the plots always have maize at different growth stages intercropped or rotated with mainly sweet potatoes, groundnuts, sugar bean and vegetables such as cabbage, night shade and spinach.

2.2. Study Design

The study adopted an explorative qualitative approach. This approach is ideal for this study since data is collected directly from people, via verbal responses [25]. Purposive sampling using a non-probability technique was selected for the present study. The study targeted the population of both young and old, male and female smallholder farmers in the study sites, as all these groups are active in farming. Smallholder farmers from the selected study sites were selected because they hold less than 2 ha of land on which they grow maize as their staple. Most elders (older than 50 years old) have a long history in farming and youth (less than 35 years) that are interested in farming are less experienced due to their age. There may be differences in the experiences of these populations which needed to be explored.

These smallholder farms fall under the traditional leadership. Thus, prior to sampling, the '*vhakoma*' (headman) was consulted in order to request permission from the '*vhamusanda*' (chief) and the agricultural extension officer for the study to be conducted. Research assistants (assigned to take notes during the sessions) were trained on protocols needed when consulting the '*vhakoma*' and during sampling.

Prior to sampling, the study site was visited from 4-12 March 2022. The purpose of the visit was to obtain all necessary documents required for ethics which included the consent from the chief, participants and the extension officer. Engagement with the extension officer of the study site assisted with organizing participants who were willing to be part of the focus group discussion. A WhatsApp group, which included the farmers (with smartphones) and extension officers, was created to enhance communication during preparations. Other farmers received communication through the extension officers and the leader of the farmer's committee.

2.3. Data Collection

Data was collected via focus group discussions, also referred to as focus interviews, intensive interviews, unstructured conversational interviews, or ethnographic interviews [26]. This method was selected because it helps in obtaining comprehensive information which includes reasons behind the answers, opinions or emotions expressed.

Focus group discussion procedure

In order to understand smallholder farmer's perception, knowledge and management practices for *S. frugiperda*, 16 focus group discussions were organised and conducted with smallholder farmers around Dzindi and Tshiombo irrigation schemes from 28 June to 6 July 2022. Twelve focus group discussions were conducted at Dzindi and four at Tshiombo irrigation scheme.

Each focus group discussion was comprised of the following groups:

- More males, $n=3$
- More females, $n=5$
- Youth (less than 35 years old) dominating, $n=3$

- Equitable representations, $n=5$

The selection of participants was assisted by agricultural extension officers in the respective study sites, who provided names of farmers who were assumed to be interested and willing to participate in the process. Farmers were approached personally to request their participation in the focus group discussion. The study was conducted in line with Covid 19 regulations. There was sanitizer at the entrance and each farmer was provided with a mask. Seats were arranged in a circle to facilitate group discussion.

The facilitator (moderator) started the session by welcoming all participants and requested for their consent to record the session on a tape recorder and if photos and videos can be taken during the discussion. A Zoom H1n portable (handy) recorder was used to record the session. At least two research assistants in addition to the facilitator were assigned to take notes. Both of the research assistants had grown up in the study area. This allowed the facilitator to focus on managing the session, ensuring that all farmers were provided the opportunity to participate in the discussions and that all topics were covered. Written comments were accepted from smallholder farmers who felt more comfortable expressing their opinions in writing. The moderator gave a brief introduction about the research objectives and overview of the topic followed by ground rules for the discussion. A printed questionnaire to obtain the socioeconomic demographic information of the smallholder farmers was distributed to the participants. Additionally, a focus group discussion confirmation letter, consent to participate in focus group discussion and letter of gratitude to the participants were distributed to the smallholder farmers.

The focus group discussion was planned so that participants could describe their knowledge and management practices used to control *S. frugiperda*. A set of focus group discussion topics had been developed prior to conducting the focus group (Appendix A). The topics included pictures of different maize lepidopteran life stages (egg, larval, pupal and adult) which gave an insight on the ability of smallholder farmers to correctly identify *S. frugiperda*. Pictures of different life stages were used to determine farmer's ability to associate these stages with *S. frugiperda*.

At the end of the session, the facilitator asked the participants to offer their opinions and reflect on the discussion. Furthermore, the notes of the research team were consolidated, to create a consensus description of the focus group discussion. The same set of topics were used at all focus group discussions to ensure consistency across different groups. Each session was aimed to last for about 1 hour 30 minutes.

2.4. Data Analysis

Smallholder farmers socio-demographic data was encoded in Microsoft Excel and imported to Statistical Package for Social Sciences (SPSS) version 25 to describe demographics in terms of frequency and percentages. Smallholder farmers knowledge, perception and management practices of *S. frugiperda* data adopted thematic analysis using steps guided according to [27]. The steps include: becoming familiar with the data by arranging and sorting transcripts, generate initial codes, search for themes, review themes, define themes followed by a final write up of the results.

2.5. Anonymity and Confidentiality

In the present study, participants identity document (ID) numbers as well as their names were not used in the analysis. Pseudonyms were used in the study. All pseudonyms that are preceded with Vho- are for the elderly whereas the ones without Vho- represent the youth.

3. Results

3.1. Demographic Information of Smallholder Farmers in the Two Study Sites

The socio-economic features of the smallholder farmers in the two study sites are provided in Table 1.

Table 1. Demographic information of smallholder farmers who participated in the focus group discussion.

Age Group	Educational Level	Years of Farming Experience.	% of all Respondents	
All Respondents (n=118)				
Less than 36 years (n=24) Males=17, Females=7	No schooling (n=0) Males=0, Females=0		0	
	Primary education (n=0) Males=0, Females=0		0	
	Secondary education (n=13) Males=9, Females=4	Less than 11 years (n=12) Males=9, Females=3	10	
		11 to 20 years (n=1) Males=0, Females=1	1	
	Tertiary education (n=11) Males=8, Females=3	Less than 11 years (n=11) Males=8, Females=3	9	
		11 to 20 years (n=0)	0	
36 to 60 years (n=47) Males=16, Females=31	No schooling (n=0)		0	
	Primary education (n=8) Males=2, Females=6	Less than 11 years (n=2) Males=1, Females=1	2	
		11 to 20 years (n=1) Males=0, Females=1	1	
		21 to 30 years (n=5) Males=1, Females=4	4	
	Secondary education (n=36) Males=12, Females=24	Less than 11 years (n=4) Males=0, Females=4	3	
		11 to 20 years (n=18) Males=7, Females=11	15	
		21 to 30 years (n=14) Males=5, Females=9	12	
		Tertiary education (n=3) Males=2, Females=1	Less than 11 years (n=1) Males=0, Females=1	1
			11 to 20 years (n=1) Males=1, Females=0	1
	More than 60 years (n=47) Males=19, Females= 28	No schooling (n=29) Male=6, Females=23	21 to 30 years (n=1) Males=1, Females=0	1
			21 to 30 years (n=27) Males=5 Females=22	23
			Less than 11 years (n=0) Males=0, Females=0	0
Primary education (n=9) Males=5, Females=4		11 to 20 years (n=2) Males=2, Females=0	2	
		21 to 30 years (n=7) Males=3, Female=4	6	
		Less than 11 years (n=0) Males=0, Females=0	0	
Secondary education (n=7) Males=6, Females=1		11 to 20 years (n=3) Males=3 Females=0	3	

	21 to 30 years (n=4) Males=3, Females=1	3
	Less than 11 years (n=0) Males=0, Females=0	0
Tertiary education (n=2) Males=2, Females=0	11 to 20 years (n=0) Males=0, Females=0	0
	21 to 30 years (n=2) Males=2, Females=0	2

The largest group (23% of all respondents) are the farmers aged over 60 years with no formal education and having 21 to 30 years of farming experience. This group is made up of 6 males and 23 females. The majority of youth were females (less than 36 years old) who received high school education and had less than 11 years farming experience. Among the adult or middle age group (36 to 60 years), a majority had secondary education and between 11 to 30 years experience.

3.2. Focus Group Discussions

3.2.1. Identification of *Spodoptera frugiperda* Life Stages by Smallholder Farmers

Farmers were provided with pictures of *S. frugiperda* life stages which included eggs, larvae, pupae and adults (moths), as well as damage symptoms caused by the maize stalkborers, *Busseola fusca* and *S. frugiperda*, without explaining to them what they were.

Eggs: Although the majority of participants confirmed that they had seen egg masses on their crops (especially maize), they were unable to correctly identify *S. frugiperda* eggs. The majority of farmers referred to *S. frugiperda* eggs as spider webs, bird droppings (guano) or a sugary substance.

Larvae: All farmers were able to identify *S. frugiperda* at its larval stage by describing its feeding habits and frass as an indication of *S. frugiperda* presence on their crops. However, the majority of farmers confused frass with *S. frugiperda* eggs. The majority of farmers were in agreement with a female farmer who indicated that *S. frugiperda* has two heads.

Vho-Maria¹: “Luvhungu lu na thoho mbili, lu la mavhele lwo toka thoho nthihi fhasi ngeni inwe yo sedza ntha, lu tshi di dzumba nga malaṭwa alwo”.

Translation: *Spodoptera frugiperda* larvae has two heads, when the one is facing down, the other one is responsible for covering the body with frass.

In addition, farmers refer to the larval stage as *Luvhungu* which is the Tshivenda local name for *S. frugiperda* (collective Tshivenda term for worms). Other Tshivenda local names used by smallholder farmers from Dzindi and Tshiombo irrigation schemes are *Mbungu*, *Tshivhungu* and *Tshirende*. Shona people who work in the farms refer to *S. frugiperda* as *Tshibagarasi* and *Makonya*.

Pupae: Only the minority of farmers had seen pupae on dry maize. Farmers refer to pupae as *Sumbandila* (meaning “lead the way”) which is the local name used to refer to any pupae. Farmers did not associate pupae with *S. frugiperda* or any other insect. They believe that pupae assist them in finding a direction if they are lost or direct them to their lost livestock. They touch pupae, then it wriggles and rests with its cremaster pointing the position towards which the livestock had moved to.

Adult moths: Adult moths are known by farmers as *Tshisusu* (which is a Tshivenda collective term for butterflies). Farmers believe that all moths that they see during the day are responsible for laying *S. frugiperda* larvae.

All farmers have encountered *S. frugiperda* damage symptoms on their maize throughout the vegetative and reproduction stages from 2016/2017 to date. *Spodoptera frugiperda* is the most damaging insect pest threatening maize farmer’s production recently. Farmers start to experience more damage especially after rainfall. The majority of these farmers believe that *S. frugiperda* arrive with the rainfall. Some farmers believe that they started to encounter *S. frugiperda* when they started to learn about improved maize cultivars because white people brought it so that they can always purchase their maize seeds instead of recycling them. Farmers were confident that they never

experienced any *S. frugiperda* long ago when they were planting their local maize seeds called *Tshikundanwedzhi*. However, *Tshikundanwedzhi* is no longer available as it is replaced by new improved seeds.

As Vho- Josephina² puts it: “Luvhungu lwo ḡisiwa nga makhuwa musu vha tshi ri ḡisela mbeu dzavho hedzi dzo no tea u rengiwa tshifhinga tshoṱhe, riṱe ri tshi lima Tshikundanwedzhi fhedzi ro vha ri sina Luvhungu”.

Translation: *Spodoptera frugiperda* was brought by scientists with their improved cultivars so that we can repurchase the seeds unlike in the past when we used to plant *Tshikundanwedzhi* (indigenous maize cultivar) that was not susceptible to any insect pest.

3.2.2. *Spodoptera frugiperda* Management Practices by Smallholder Farmers

Chemical control by use of insecticides was reported as the main control of *S. frugiperda* by all farmers. In exception to Dzindi irrigation farmers who have adopted Bt maize, almost all farmers have not yet adopted alternative methods to chemical control such as biological, cultural practices (such as Push Pull Technology), indigenous knowledge, or the use of monitoring tools (traps) for the management of *S. frugiperda*. According to the majority of farmers, insecticides are modern ways of controlling insect pests.

Vho-Siaga³: “Ri shumisa mishonga, ndi nnyi ane a do fara mafola nga tshimanzhe-manzhe”

Translation: We only use pesticides to control *S. frugiperda* as it is the modern way of controlling insects and we have neglected the indigenous knowledge of controlling insects.

Source of insecticides by smallholder farmers

All smallholder farmers receive insecticides once a year as part of a government subsidy through the Department of Agriculture, Land Reform and Rural Development’s Farmer Support Programme (FSP). Farmers reported that they receive insecticides such as include Methomyl 200 SL (WHO class IA), Methomex ®900 SP (WHO class IB), Tamron 505 SL MSDS (WHO class IB), Masta 900 SP (WHO class IB), while they purchase some from local certified retailers (mainly NTK, known as *Koporasi* by farmers) (Table 2).

Table 2. Types of insecticides used by smallholder farmers from Dzindi and Tshiombo irrigation schemes.

Insecticide	WHO Group	Active Ingredient	Chemical Group
Trade name			
Adama abamectin 6		Abamectin	Avermectin
Allice 222 SL	4A	Acetamiprid	Neonicotinoid
Avi guard	IB	Mercaptothion	Organophosphate
Cartap	14	Cartap hydrochloride	Cartap hydrochloride
Cypermethrin 200 EC	3A	Cypermethrin	Pyrethroid
Hunter 24SC	13	Chlorfenapyr	Pyrrole
Kemprin 200 EC	3A	Cypermethrin	Pyrethroid
Kombat	3	Mercaptothion	Organophosphate
Malathion			
Makhro cyper	3A	Cypermethrin	Pyrethroid
Malasol	IB	Mercaptothion	Organophosphate
MECTI	6A	Abametin	Avermectin
Methomex ®900	II	Methomyl	Carbamate
Methomyl 200 SL	1A	Methomyl	Carbamete
Phosdrin ®500 SL	IB	Mevinphos	Organophosphate
Stalkborer granules	II	Carbaryl	Carbamate
Steward ®150 EC	II	Oxadiazine	Indoxacarb

Supermetrin	3A	Cypermethrin	Pyrethroid
Tamron 585 SL	IB	Methamidophos	Organophosphate
Warlock® 19.2 EC	6	Emamectin benzoate	Avermectin

Notes: WHO Recommended classification of pesticides by hazard and guidelines to classification. 1a=Extremely hazardous;1b=highly hazardous; II=Moderately hazardous; III=Slightly hazardous.

Frequency of insecticide application

Farmers apply insecticides as a preventative measure against *S. frugiperda*. They start to apply insecticides before they encounter any damage symptoms. A male farmer reported applying insecticides on soil immediately after ploughing, once noticing white web-like substances on the soil. According to the farmer, the white web-like substances represent the presence of *S. frugiperda*. The majority of farmers start to apply insecticides when maize is at the two leaf stage and stop applying at the reproductive stage (tassel formation). All farmers use knapsacks or mist blowers to apply insecticides.

Effectiveness of insecticides used by smallholder farmers against *S. frugiperda*

Farmers from Dzindi irrigation scheme reported Stalkborer granules and Tamron as the most effective insecticides to control *S. frugiperda*. However Tamron is no longer easily available. Farmers from Dzindi irrigation scheme report that Methomax is no longer effective while with Tshiombo farmers it is the most effective insecticide. The majority of farmers at Tshiombo irrigation scheme find insecticide cocktails more effective in controlling *S. frugiperda*; they mix Ampblingo, Adama and Methomex. One male farmer from Dzindi irrigation scheme mixes any insecticides (even for other lepidopterans) he has in his storage as a preventative measure against *S. frugiperda*. Other cocktails mixed to control *S. frugiperda* by farmers includes Melasol, Allice 222 SL and Cartap and Allice 222 SL, Cartap and Methomex ®900. Farmers believe that cocktails enhance efficacy and reduce the smell (odour) of insecticides.

Simbarase⁴: “Ri vha ri khou zama plane uri Luvhungu lu fe”.

Translation: We are trying our luck to kill *S. frugiperda*.

The use of Bt maize by smallholder farmers

In the present study, knowledge about GM maize varies among farmers. Tshiombo irrigation scheme farmers lack access to information about GM maize technology. In contrast, Dzindi irrigation farmers have adopted GM maize technology after receiving training from a seed company and a demonstration in a trial plot. Farmers prefer GM maize seeds because of increased yield due to much bigger grains and for the fact that they do not have to use insecticides to control *S. frugiperda*.

Vho-Mudau⁵: “Mbeu hei i sa liwi i a ri thusa ngauri a ri tsha hwala tshigubu tsha mushonga”

Translation: GM maize varieties are important to us because we no longer apply pesticides to control *S. frugiperda*.

Farmers source their seeds from NTK. The most preferred cultivar due to a bigger size grain is DKC 7374 BR. The majority of farmers did not know the difference between Bt (BR) and Roundup ready (R) maize cultivars. As a result, farmers refer to all these cultivars as Roundup.

Bt compliance by smallholder farmers

When farmers who cultivate Bt/BR maize were asked about the refuge, specifically if they knew what it was and the requirements for planting a non-Bt maize refuge next to their Bt maize fields, answers differed greatly among farmers. Farmers referred to non-Bt maize refuge as a free token or a gift for purchasing the seeds.

Vho-Masindi⁶: “Heiḽa phakhethe yo no rengisiwa na mavhele a sa liwi ndi basela.”

Translation: Refuge maize is a free token (a complimentary gift after purchasing Bt maize).

Farmers who received training on GM/ Bt maize technology referred to it as a *security guard* or a *fence* which is used as a protective barrier against damage by *S. frugiperda* on Bt maize. All surveyed farmers did not plant non-Bt refuge maize correctly. Some farmers plant refuge in their homes and Bt maize in their field. Some do not plant a refuge at all, whereas others only plant if they run out of Bt maize seeds and still have available space for planting. Some farmers intercrop Bt maize with non-Bt refuge maize. Some farmers recycle Bt maize because it is their traditional way of selecting the best cultivars to be used in the second season. They believe that seed companies want to make money and

that is why they are asked to buy seeds instead of recycling the seeds. They believe that recycling Bt will provide the same insecticidal effects towards *S. frugiperda*.

Other management practices of *S. frugiperda* by smallholder farmers

When farmers were provided with an opportunity to mention some of the indigenous/traditional ways of controlling *S. frugiperda* they mentioned practices that they used in the past to control other insects but they have not tried them on *S. frugiperda*. These practices include intercropping sugarcane with maize, morning sprinkling of nicotine aqueous solution (soaked overnight), and aqueous solution of the Lemon Bush (*Lippia javanica*), known as *Musudzungane*. The majority of farmers are reluctant to try these methods on *S. frugiperda*, because they were used in the 'olden days' and were replaced by insecticides.

Vho-Rosinah⁷: "Ndi tshikhuwa, ri shumisa mushonga, zwa mafola ndi zwa kale"

Translation: We cannot use nicotine leaves in the modern days, we only prefer insecticides.

4. Discussion

This study provided insights on Dzindi and Tshiombo irrigation scheme farmers perception and knowledge about *S. frugiperda* (identification, its biology or life stages), as well as the way they manage this insect pest on maize. The results indicated that all surveyed farmers perceived *S. frugiperda* as the most devastating insect pest of maize. This is consistent with smallholder farmers from Ghana who associated *S. frugiperda* with "witchcraft", the works of their enemies, anger of the gods and bad luck on their government [23]. In contrast, some Ugandan farmers believe that it is not a threat to maize production because they find it easy to manage, provided they have the correct and effective insecticides [28]. Dzindi and Tshiombo irrigation scheme farmers knowledge about *S. frugiperda* is limited and they differ in the strategies they use to control *S. frugiperda*.

Oviposition by insect pests act as an early warning signal for its presence. Therefore, smallholder farmers inability to identify *S. frugiperda* eggs in the study area means that they are unable to control it at an early stage of development. Those smallholder farmers in sub-Saharan Africa who are able to identify *S. frugiperda* eggs crush them in order to reduce the infestation level which is the most effective timing of control before they move into the maize whorl [29]. In instances where pheromone lure traps are used to monitor for *S. frugiperda*, it is important for farmers to correctly identify the adults (moths), as some of the moths from different species may be attracted on the trap making it difficult to quantify the level of infestation. For example, Nonanal *S. frugiperda* sex pheromone-baited traps captured 105 *S. frugiperda* males, one female and 15 noctuid moths species [30]. Therefore, farmers inability to correctly identify *S. frugiperda* life stages (egg, larva, pupa and adult) has an implication in its control.

Farmers were able to identify the larvae, but knowledge about *S. frugiperda* larvae identification varied among smallholder farmers. The majority (91%) of farmers in Zambia [24], Ethiopia and Kenya [19] were able to correctly identify *S. frugiperda* larvae whereas some of the farmers and extension officers in Mozambique still confuse it with other lepidopteran larvae such as stemborers [21]. Smallholder farmers at Dzindi and Tshiombo use several local names such as *Luohungu*, *Makonya* and *Tshibaragasi* to refer to *S. frugiperda* larva. It thus appears that it is common for most smallholder farmers in sub-Saharan Africa to be able to identify the insect pest by its local name [31,32]. Therefore, it is important for extension officers to familiarize themselves with the local insects names used by farmers so that they can provide appropriate advice to farmers.

Smallholder farmers' limitations of understanding *S. frugiperda* life stages is an indication of a poor understanding of its biology, perhaps partly because *S. frugiperda* is a new invasive pest in sub-Saharan Africa [33]. Knowledge of the biology and behaviour of *S. frugiperda* enable farmers to target planting time and ensure correct timing of control (when the insect is in the most vulnerable stage) [20]. Monitoring and scouting requires knowledge of insect pest biology, its correct identification coupled with correct sampling methods, and smallholder farmers at both study sites lacked those attributes. Farmers did not know anything about the use of traps or standardized sampling techniques. In contrast, smallholder farmers from Cameroon monitor and scout their maize fields immediately four to five days after planting in order to evaluate damage symptoms and frass on the

stem which is a positive indicator of *S. frugiperda* presence [34]. The most effective *S. frugiperda* monitoring was adopted by smallholder farmers from Rwandan communities who received smart cell phones installed with Fall Armyworm Monitoring and Early Warning System (FAMEWS) and sex pheromone lures with bucket traps from FAO to assist them with early warning of *S. frugiperda* [35]. The lack of adoption to scouting or monitoring tool (Food and Agricultural Organization of the United Nations) of the Dzindi and Tshiombo irrigation scheme farmers may be attributed to lack of access to technology, skills and training on insect pest scouting.

All sampled farmers from both sites relied on insecticides as the main control for *S. frugiperda*. This is consistent with other smallholder farmers in African countries such as Botswana [36], Kenya and Ethiopia [19], Malawi [20], Mozambique [21], Zimbabwe [22] and Ghana [23]. This reliance of insecticides by farmers may be due to the fact that the response of many African governments to *S. frugiperda* invasion was the immediate registration followed by farmers subsidy of pesticides for its control [12]. For instance, the South African government registered about 50 insecticides in response to *S. frugiperda* invasion and annually subsidize smallholder farmers with some of these insecticides [37]. This is consistent with the government in Ghana, which supplied smallholder farmers with pesticides as part of a planting for food and job initiative [23]. Rwanda deployed their army in order to halt the spread of *S. frugiperda* through distribution of pesticides and hand-picking of larvae on farmer's fields [38]. Of great concern is that the farmers at Dzindi and Tshiombo irrigation schemes use insecticides that are highly toxic (falls under category WHO IA, 1B and II), among which is Tamron banned by the United States in 2009 [39] and also banned in Zimbabwe, due to its high toxicity to non-target organisms including humans [40]. Highly hazardous pesticides from WHO class 1B and II are not recommended for use by smallholder farmers as they lack knowledge and resources for protecting themselves against these harmful pesticides [12]. Selection of these highly hazardous pesticides by farmers at Dzindi and Tshimbo irrigation schemes may be attributed to availability, or accessibility and efficacy coupled with farmers experience on the insecticide.

Farmers have the tendency to try every chemical or material rumoured to assist in controlling *S. frugiperda* due to desperation and lack of knowledge on other alternative control strategies of the pest [40]. Some smallholder farmers at Tshiombo irrigation scheme were advised by their neighbours to use insecticide cocktails in order to enhance efficacy. This is consistent with farmers in Macate, Zimbabwe who mix two or more insecticides for *S. frugiperda* control [21]. The efficacy of insecticide cocktails and its cost effectiveness needs to be evaluated further.

Perception of insecticide efficacy on *S. frugiperda* vary among smallholder farmers worldwide. Smallholder farmers from Dzindi irrigation scheme reported that Methomex ®900 SP is no longer effective in controlling *S. frugiperda*. This is consistent with farmers from Mankweng and Ga-Mashashane (about 300 km from Dzindi irrigation scheme) [41] and farmers from China's Yunnan province [42], Kenya [19] and Zimbabwe [22] who reported that Methomex ®900 SP has become less effective in controlling *S. frugiperda*. However, the majority of farmers in Ethiopia indicated that Ethiolathion, malathion and chlorpyrifos were effective in controlling *S. frugiperda* [19].

Variations in the efficacy of different insecticides used to control *S. frugiperda* may be attributed to factors such as timing of application. As farmers from Dzindi and Tshiombo irrigation scheme lack monitoring tools and scouting skills, it is possible that in most cases they apply insecticides in the absence of the vulnerable life stage of *S. frugiperda*. Insecticides are only effective on early larval instars of *S. frugiperda* as older instars hide on maize whorls, feeding and using frass as a covering [43] or use maize reproductive parts such as the whorl, ear or kernel to induce a protection to insecticide application [13]. The best time of day for insecticide application is at dawn because young larvae hide in maize whorls during the day and become active during the night [10]. However, farmers at Dzindi and Tshiombo irrigation schemes do not consider timing of application. They apply insecticides anytime of the day depending on the availability of labour or family members willing to assist them.

Although there is no official confirmation of *S. frugiperda* resistance to insecticides used, it is not known if there was a *S. frugiperda* population already resistant to insecticide groups upon its arrival in South Africa [12]. In the case of Dzindi and Tshiombo irrigation schemes, similar to Mankweng

and Ga-Mashashane in Limpopo Province, farmers reported that they are provided with insecticides from the same chemical group (carbamates) and as a result *S. frugiperda* might have already developed resistance due to repeated application. In addition, the registered insecticides for *S. frugiperda* falls under insecticide groups that *S. frugiperda* has developed resistance in Puerto Rico and Mexico [44] and China [45]. Therefore, further screening of possible insecticide resistance of *S. frugiperda* in South Africa is needed.

Effective control of *S. frugiperda* requires Integrated Pest Management (IPM) using the coordinated integration of multiple and complementary control strategies that reduce insect pest population in a safe, cost effective and environmentally friendly manner [46]. Smallholder farmers from Benin use insecticides (such as Emamectin benzoate, acetamiprid, cypermethrin, chlorpyrifos-cyhalothrin and emamectin benzoate) with botanical pesticides (such as Yellow nutsedge, chan, shea tree, neem, tamarind and soybean) [16]. Farmers from upper west regions of Ghana alternate insecticides with early planting, use of improved seeds, uprooting and disposal of infested plants, use of washing detergent (OMO), and handpicking of eggs and larvae [47]. However, smallholder farmers at Tshiombo irrigation scheme are solely dependent on insecticides without considering other alternatives in order to enhance control of *S. frugiperda*. Farmers from Dzindi irrigation scheme indicated indigenous knowledge to manage insect pests, but have neglected those practices. This is consistent with farmers from Umtata (Eastern Cape), South Africa who have neglected indigenous knowledge of controlling some maize insect pests [48]. This may be attributed to the promotion of pesticides.

Only farmers at Dzindi irrigation scheme have adopted Bt maize. This might be attributed to the fact that only Dzindi irrigation scheme received training on Bt maize. Similarly, in the Eastern Cape, the farmers who attended the programme on GM maize were the ones who adopted the technology [49]. Dzindi irrigation scheme farmers indicated that regardless of high seed cost, GM maize is economically effective. According to these farmers, Bt maize benefits include an increased yield and less labour due to non or less insecticide application. This is consistent with the results from the demonstration of Bt maize to smallholder farmers in Mpumalanga, Gauteng, North-West, Free State, Eastern Cape and KwaZulu-Natal provinces of South Africa that indicated higher yield due to less insect damage on GM maize, reduce need for scouting and less labour for smallholder farmers who relied on knapsack for insecticide application as compared to conventional maize as main advantages of this technology [50]. In contrast farmers in Christiana, North West province of South Africa viewed GM maize as non-beneficial due to *Busseola fusca* developing resistance in their area [51].

GM maize growers are required to plant a refuge area of non-Bt maize adjacent to their Bt maize fields in order to delay resistance development. Current refuge requirements are either a 20% non-Bt planted (refuge) which may be sprayed with insecticides or a 5% refuge area that may not be sprayed [52]. Dzindi irrigation scheme farmers have been non-compliant to GM maize planting. Most farmers did not plant refuge because they were not aware of the importance and consequences associated with not planting refuges. Farmers in Christiana and Standerton in Mpumalanga, South Africa, find refuge planting as being labour intensive and time consuming [53]. As a result those who planted refuge preferred planting a 5% refuge rather than a 20% refuge, and applied insecticide on the refuge, resulting in it being ineffective. Non-compliance to refuge requirement by smallholder farmers at Dzindi irrigation may be attributed to lack of training on Bt compliant requirements. For example, knowledge about Bt compliance increased after farmers from North Carolina, USA receive training on the purpose and necessity of non Bt maize refuge [55]. There is a need for proper training of farmers on Bt technology at Dzindi irrigation scheme and a need for regular evaluation of possible *S. frugiperda* Bt resistance.

5. Conclusions

Although the study focus was in Limpopo Province, findings could have relevance in smallholder farmers around sub-Saharan Africa experiencing *S. frugiperda* invasion. Despite government interventions in regular supply of pesticides to smallholder farmers in order to halt *S. frugiperda*, it still remains a devastating insect pest of maize. Farmers' limitations in understanding

the biology and monitoring of *S. frugiperda* and other alternative management strategies indicates that regular training and education of farmers in both Tshiombo and Dzindi irrigation schemes is needed. This is also considering that most of the farmers in the two study sites were elderly and illiterate and as a result may require more support in handling of pesticides and their risks associated with their use. Regular screening of possible *S. frugiperda* Bt and insecticide resistance is necessary and alternative indigenous knowledge of controlling *S. frugiperda* should be promoted.

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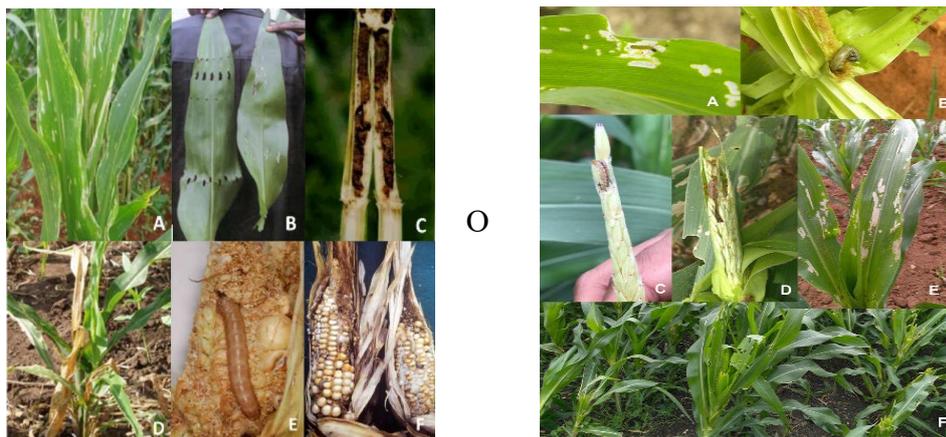
Appendix A

Topics for discussion at Focus Group Discussion

1. Which crops and cultivars do you cultivate?
2. Have you seen the following stages of this insect on your crops?



Have you seen the following damage symptoms on your maize?



3. What do you call these insect pests?
4. What do you do when you see these insect pests?
5. Who gives you advice on the control strategy that you have selected to control these insect pests?
6. When do you apply that control strategy?
7. If you apply the control strategy, do you see any changes on the numbers of the insect pests?
8. If you observe any changes after control, how long do you observe those changes?
9. Do you think this insect pest affects your yield? Please elaborate

Is there anything that you would like to add or comment on?

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